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AFML-TR-72-137

# ACCELERATED WEATHERING OF POLYAMIDES, AROMATIC POLYAMIDES, AND POLYBENZIMIDAZOLE FABRICS

*DONALD R. MAY, JR.*
*JACK H. ROSS*

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TECHNICAL REPORT AFML-TR-72-137

OCTOBER 1972

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AIR FORCE MATERIALS LABORATORY
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# ACCELERATED WEATHERING OF POLYAMIDES, AROMATIC POLYAMIDES, AND POLYBENZIMIDAZOLE FABRICS

*DONALD R. MAY, JR.*

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## FOREWORD

This report was prepared by the Fibrous Materials Branch, Nonmetallic Materials Division, Air Force Materials Laboratory, Air Force Systems Command. It was initiated under Project 7320, "Fibrous Materials For Decelerators and Structures", and Task 732002 "Fibrous Structural Materials" with Mr. Donald R. May, Jr. acting as Project Engineer.

This report has been reviewed and is approved.

T. J. Reinhart Jr

T. J. REINHART, JR., Chief
Composite and Fibrous Materials Branch
Nonmetallic Materials Division

ABSTRACT


Parachute pack fabrics utilized in personnel decelerators are subjected to extensive solar radiation (primarily U-V) during in flight missions and related ground handling situations.

Parachute pack replacements during the service life of a parachute results in additional costs, unnecessary and excessive out of commission time, and the requirement for larger inventories.

The data presented herein covers the work accomplished on an internal program to study the reaction and resistance of various types of actual and candidate parachute pack fabrics to ultra-violet exposure.

As expected Type 330 nylon was the most U-V resistant material evaluated. PBI-II and dyed Nomex had approximately the same percentage retention of breaking and tear strength but were not equal to U-V resistant nylon.

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# SECTION I

## INTRODUCTION

Some of the more readily recognized requirements for fibrous materials in Air Force end items and applications include uniform, flight and protective clothing, life support equipment and decelerator materials. In the area of materials for personnel decelerators, the overall cost could be reduced and the out-of-commission time decreased by utilizing a more durable parachute pack fabric with a service life more closely approximating that of the canopy. The more durable pack fabric must also meet improved reliability and safety when exposed to fire. Even slight flame impingement on the present nylon pack can result in fusion of system components and failure of the canopy to deploy. The search for new or improved fibrous materials for aircrew protection from fires is continuous and unrelenting. Stanton (Ref 1) evaluated the thermal characteristics of readily available and experimental fabrics intended for use in life support systems for aircrew protection. Fabrics evaluated were both combustible and non-combustible and were obtained from Air Force Inventory and various Industrial Sources. The Air Force fabrics ranged from the flammable but extremely comfortable cottons to the equally comfortable but totally nonflammable polybenzimidazole, (PBI). Beta Glass, Kynol, Nomex, Durette, Fi-Pro and F-Fabric comprised the group of Industrial Fabrics which were evaluated and characterized. It was only natural that fabrics suitable for personnel protection would find usage in related life dependent applications requiring the same degree of operation reliability. From Stanton's (Ref 1) findings, Nomex and PBI therefore

appear desirable for parachute pack and harness applications. They possess [illegible] of the more desirable characteristics and properties of nylon but have much higher thermal stability, and do not support combustion or melt when in contact with flame. Nomex** is readily available commercially while the availability of PBI is currently more limited.

Operational experience has shown that the parachute pack is subjected to a variety of physical and chemical conditions which can cause deterioration; however, the degradation necessitating frequent replacement of the pack fabric is largely attributable to solar radiation.

The work presented herein covers an investigation of the effects of accelerated aging on various type pack fabrics for the purpose of predicting those best suited for Air Force operational use. Additionally, it expands the data base on thermally suitable fabrics for personnel protection by providing ultraviolet reaction information which heretofore was not available. The degree of degradation occurring in a material is contingent upon the environment to which exposed. Accelerated weathering and natural weathering are not directly and infallibly transposable; however, fabric reaction to accelerated weathering is an indicator of what can be anticipated and expected under natural conditions.

**TRADE MARK. E. I. du Pont de Nemours

## TABLE II

## EVALUATION PROGRAM

Seven (7) fabrics in use or being considered for use in the manufacture of parachute packs were investigated and the findings are reported. Of the three pack fabrics currently in service, two (2) conform to the specification requirements of MIL-C-38351 while the other fulfills those outlined in MIL-C-7219C, Table I. The two (2) candidate materials consist of a fire resistant Durette (specially treated Nomex) and PBI fabrics possessing physical properties as near those of specification nylon pack materials as was available, Table I and II.

Control samples and test specimens were prepared from each of the selected fabrics in accordance with Federal Test Method Standard No. 191. Preparation of specimens for both warp and filling testing was considered redundant since both would reflect approximately the same degree of degradation and subsequent change in properties. On this premise, the determination to test only in the warp direction was made.

Properties and characteristics of the control samples including such attributes (properties) as yarn count, weight, thickness, breaking strength, elongation and tear strength were determined Table II.

The test specimens were exposed for periods of 50, 100 and 150 hours in the accelerated Weathering Unit, Atlas-Weatherometer, using vertically mounted Sunshine copper coated carbons, with filters of Corex D glass and without a water spray. Upon completion of accelerated weathering, the specimens were allowed to condition for a minimum of 24 hours at standard conditions (temp $70^{\circ}F \pm 2^{\circ}$ and 65%RH + 2%) prior to testing. After

TABLE I

Identification and Description of Materials

| Fabric | Applicable Specification | Color/State | Treatments Modifications | Status | Sample Identification |
|---|---|---|---|---|---|
| Nylon | MIL-C-72196 Type II | Sage green | None | In Use | Nylon |
| Nomex** | MIL-C-38351 Type I Class II | Natural | None | In Use | Nomex |
| Durette* | Approximates MIL-C-38351 Type II Class I | Natural (gold) | Fire Retardant | Candidate | Durette |
| Nomex | MIL-C-38351 Type II Class I | Olive green | None | In Use | Nomex-OG |
| PGI-I&II | | Natural (gold) | None | Candidate | PBI |

*Trade Mark - Monsanto Company
**Trade Mark - E. I. dupont de Nemours, Inc.

Note: PBI Fabrics are currently undergoing service tests in parachute packs. However, the nonavailability of same necessitated the use of an alternate fabric possessing physical properties near those of specification pack materials.

TABLE II

Physical Properties of Materials

| Property | | Specimens Cloth, Parachute Pack | | | | | |
|---|---|---|---|---|---|---|---|
| | | Nylon | Nomex | Durette | Nomex-OG | PBI-I | PBI-II |
| Original Fabric | | | | | | | |
| Weave | | Plain | Plain | Plain | Plain | Plain | 2/2 Twill |
| Yarns/Inch | W | 63 | 63 | 64 | 62 | 42 | 71 |
| | F | 45 | 49 | 47 | 47 | 42 | 71 |
| Thickness, inches | | .013 | .015 | .013 | .012 | .011 | .011 |
| Weight (oz/yd$^2$) | | 6.59 | 6.62 | 6.90 | 6.45 | 4.86 | 4.30 |
| Breaking Strength (lbs/In) | W | 333.8 | 293.6 | 175.2 | 229.0 | 160.2 | 118 |
| Elongation (%) | W | 39 | 45 | 28 | 40 | 26 | 19.5 |
| Tear Strength (lbs) | W | 42 | 26 | 10 | 21 | 38 | 11.7 |

*See Table IX

accelerated aging and conditioning, breaking strength (Figure 1) and tearing strength (Figure 3) properties were ascertained and compared with the control to determine the resistance to deterioration. Resistance to deterioration or degradation is indicated by that strength (% of original) remaining or retained after exposure (Figures 2 and 4). Tearing and breaking strengths were determined by the tongue tear (5134) and ravel strip (5104) methods outlined in Federal Test Method Standard No. 191. All tests using the Instron Tensile Tester were made by a single operator in order to minimize variations in both procedure and results obtained. The Instron Tensile Tester was adjusted to obtain a jaw separation speed of 12 $\pm$ 0.5 inches/minute with a 3-inch gauge length for the aforementioned tests and an average of five (5) samples was used for each evaluation and determination.

FIGURE 1

BREAKING STRENGTH AFTER WEATHEROMETER EXPOSURE

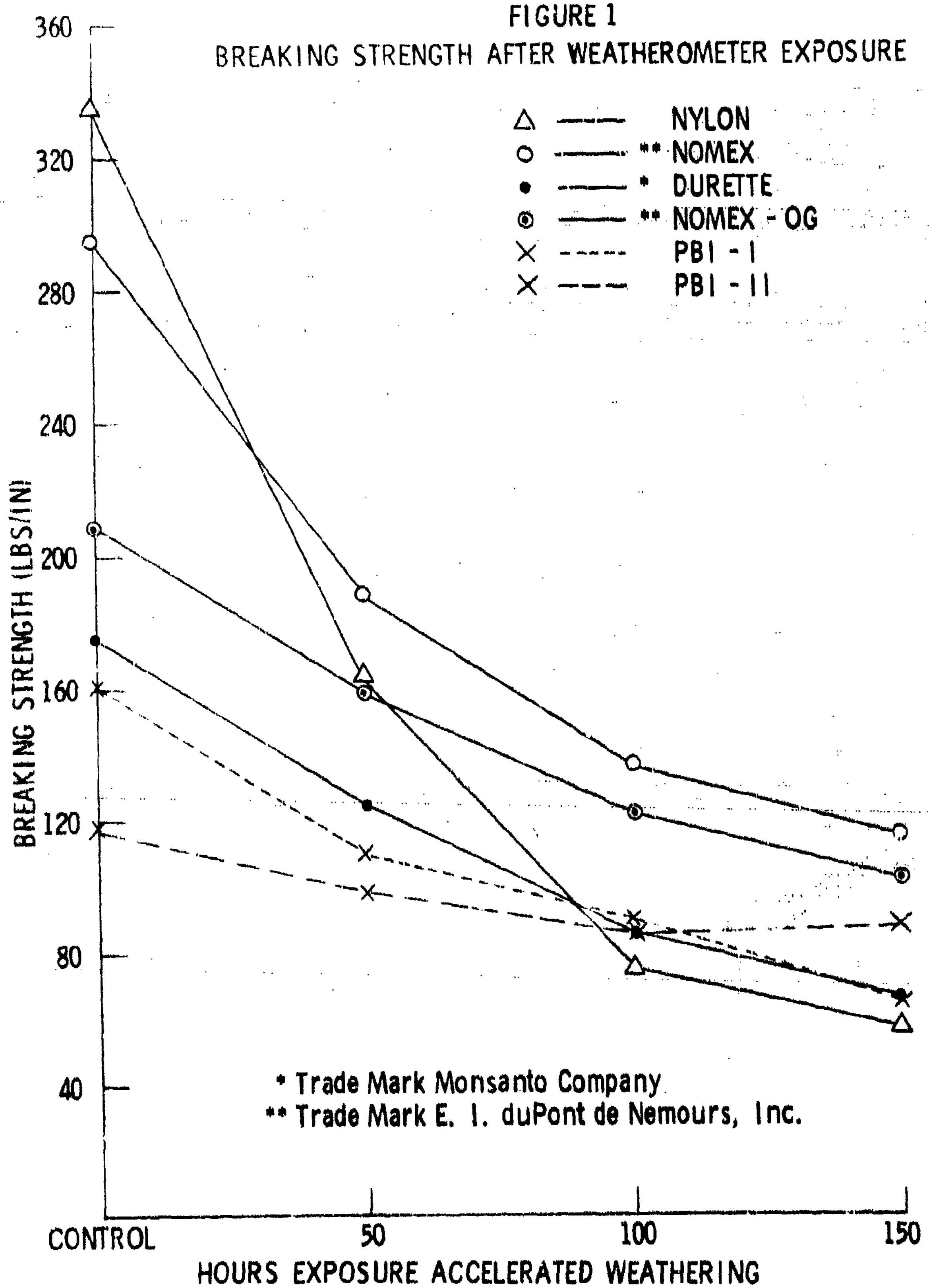

FIGURE 2
AVERAGE LOSS OF BREAKING STRENGTH PREDICATED ON
PERCENT (%) OF ORIGINAL RETAINED

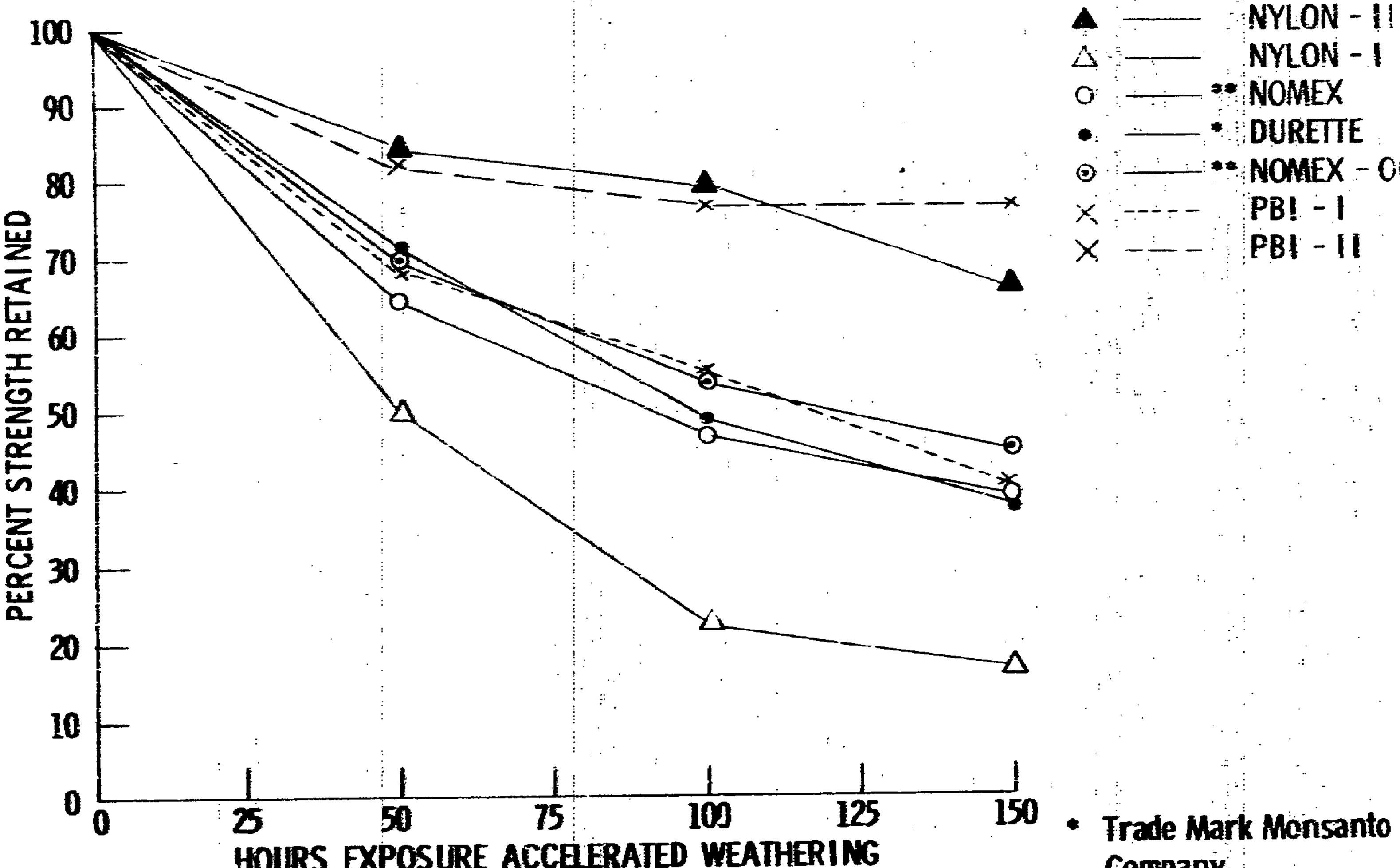


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FIGURE 3
TEARING STRENGTH AFTER WEATHEROMETER EXPOSURE

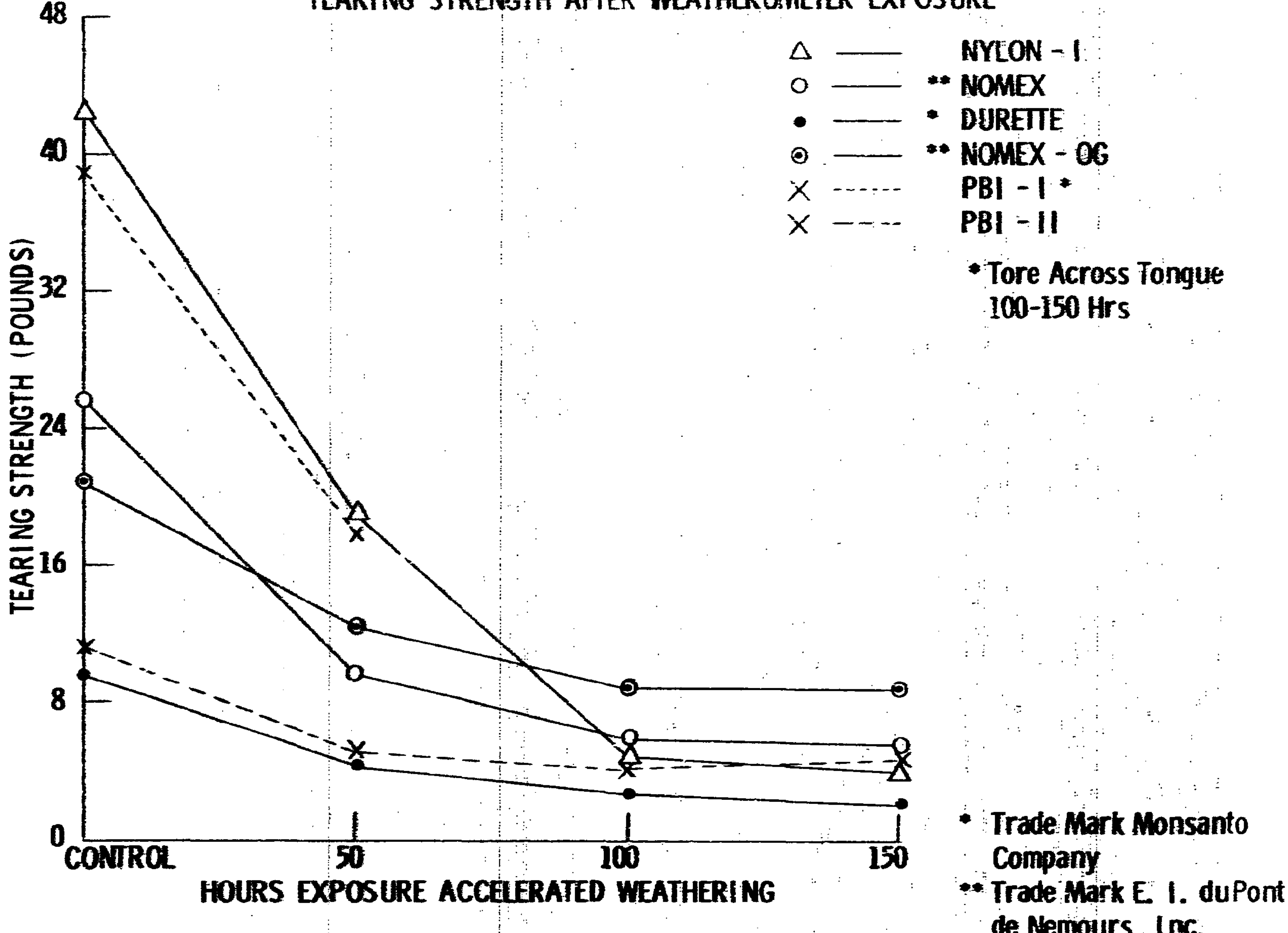
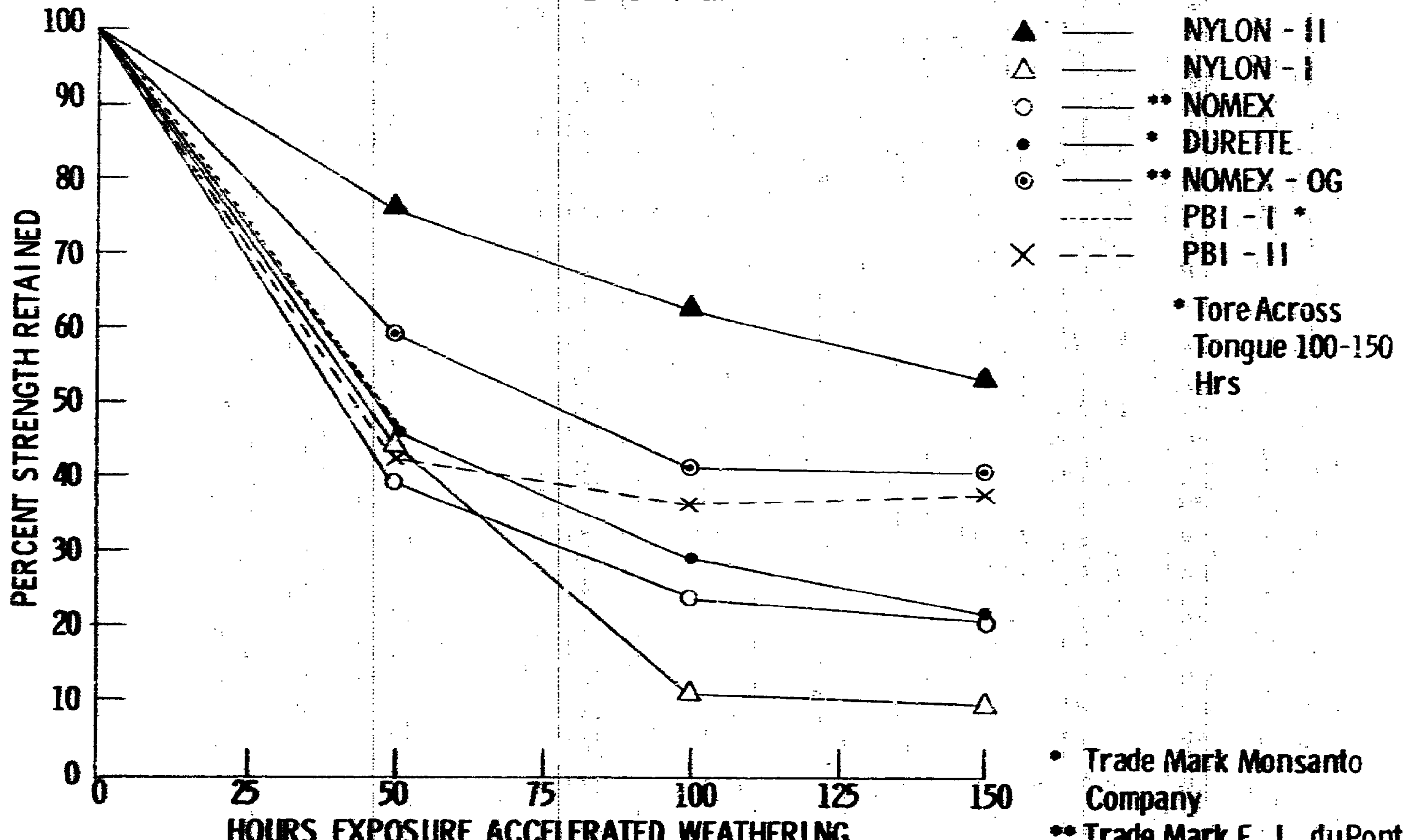


FIGURE 4

AVERAGE LOSS OF TEARING STRENGTH PREDICATED ON PERCENT (%) OF ORIGINAL RETAINED

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## SECTION III

## DISCUSSION

McGrath Ref. 2 & 4 conducted accelerated Weathering versus Outdoor Exposure Tests and concluded that correlation of the results is neither universal nor unequivocal. The author reported however, that accelerated weathering reaction is a reasonable indicator of the fabrics subsequent weathering expectant reaction to outdoor exposure performance in the natural environment. These conclusions and findings were substantiated by Hindson (Ref. 6) who advocates the use of accelerated weathering exposures to predict material performance and avoid its acceptance and/or usage if it is apparent that rapid degradation will occur from natural outdoor weathering.

Previous work by Hargeaves, McGrath and Boone (Ref. 3, 4, and 5) indicate that 100 to 150 hours of rapid aging under the carbon arcs of the weatherometer results in a degree or state of degradation approximating that which occurs after six weeks to three months exposure to the natural elements However, Ross and Dauksys (Ref. 7) report that upon comparing fabric data obtained from outdoor samples to the accelerated weathering samples, it was most significant that outdoor exposure caused more serious degradation than artificial weathering.

It therefore appears that in most situations the use of the weatherometer to predict a material's subsequent performance is sound since degradation in the natural environment would very probably be more severe than the indicated by the laboratory test.

In consonance with the above, and upon termination of accelerated aging for each of the aforestated exposure periods, the specimens were removed from the Weatherometer and the breaking strength, tearing strength and elongation were determined. The breaking strength data are presented in Figures 1 and 2, and Table IV & V, while tearing strength is shown in Figures 3 and 4, and Tables VI & VII and elongation attributes are contained in Table III. During analysis of the data, the breaking strength and tear strength of the nylon 6-6 fabric came under suspicion due to the very low % retained mechanical properties. The source of the fabric was questioned and it was established that the fabric had been in AF stock for a number of years. This led to the conclusion that the nylon yarn used was not U-V and heat resistant. A sample of fabric was obtained which was known to be woven of du Pont's Type 330 yarn. This is labelled as nylon II in Table IX and X. Similarly the data on the PBI-I fabric did not agree with that of Ross and Opt (Ref. 8). Another PBI fabric (in a lighter weight) made from a different (and newer) batch of continuous filament yarn (PBI-II) was exposed in the weatherometer with nylon II for 50, 100, and 150 hours under the same conditions already described. The data shown in Table VIII and X confirmed the earlier data (Ref. 8).

The nylon 6-6 yarn with the built-in U-V inhibitor was in all cases except PBI-II the most resistant to degradation at all exposure levels. The PBI-II was quite resistant to U-V. As previously reported by Ross and Opt (Ref. 8), PBI has the capability of retaining properties when exposed to U-V, but this property appears to be dependent on the quality of the

TABLE III

Fabric Elongation (%) At Break After Accelerated Aging

| Aging Exposure | | Specimens Cloth, Parachute Pack | | | | |
|---|---|---|---|---|---|---|
| | | Nylon | Nomex** | Durette* | Nomex-OG | PBI-II |
| Control | Average | 39 | 45.3 | 27.9 | 40.3 | 19.6 |
| Fifty (50) Hours | Average | 26 | 21.6 | 14.9 | 20.7 | 12.6 |
| One Hundred (100) Hours | Average | 15.5 | 19 | 10.3 | 16.0 | 7.4 |
| One Hundred Fifty (150) Hours | Average | 12.6 | 16.4 | 7.8 | 14.9 | 6.6 |

*Trade Mark Monsanto Company
**Trade Mark E.I. dupont de Nemours, Inc.

TABLE IV

Fabric Breaking Strength (lbs/In) After Weatherometer Exposure

| Aging Exposure | | Specimens Cloth, Parachute Pack | | | | |
|---|---|---|---|---|---|---|
| | | Nylon | Nomex | Durette | Nomex-OG | PBI-II |
| Control | Average | 333.8 | 293.6 | 175.2 | 229.0 | 118.0 |
| Fifty (50) Hours | Average | 161.6 | 187.0 | 125.4 | 159.2 | 97.5 |
| One Hundred (100) Hours | Average | 73 | 136.4 | 84.4 | 122.2 | 89.6 |
| One Hundred Fifty (150) Hours | Average | 57.1 | 114.6 | 66.2 | 102.6 | 89.7 |

TABLE V

Strength Retained After Weatherometer Exposure
(% of Original)

| | | Specimens Cloth, Parachute Pack | | | | |
|---|---|---|---|---|---|---|
| | | Nylon | Nomex | Durette | Nomex-OG | PBI-II |
| Control | (lbs) Break Strength | 333.8 | 293.6 | 175.2 | 229.0 | 118.0 |
| Fifty (50) Hours | (lbs) Break Strength | 161.6 | 187.0 | 125.4 | 159.2 | 97.5 |
| | % Retain | 48.4 | 63.69 | 71.60 | 69.6 | 82.6 |
| One Hundred (100) Hours | (lbs) Break Strength | 73.0 | 136.4 | 84.8 | 122.2 | 89.6 |
| | % Retained | 21.90 | 46.45 | 48.40 | 53.40 | 76.0 |
| One Hundred Fifty (150) Hours | (lbs) Break Strength | 57.1 | 114.6 | 66.2 | 102.6 | 89.7 |
| | % Retain | 17.05 | 39.03 | 37.80 | 44.90 | 76.1 |

TABLE VI

Fabric Tearing Strength (lbs) After Weatherometer Exposure

| Aging Exposure | | Specimens Cloth, Parachute Pack | | | | |
|---|---|---|---|---|---|---|
| | | Nylon | Nomex | Durette | Nomex-OG | PBI-II |
| Control | Average | 42.4 | 25.8 | 9.8 | 21.1 | 11.7 |
| Fifty (50) Hours | Average | 19 | 9.8 | 4.5 | 12.5 | 5.2 |
| One Hundred (100) Hours | Average | 4.9 | 5.9 | 2.8 | 8.9 | 4.3 |
| One Hundred Fifty (150) Hours | Average | 4.0 | 5.5 | 2.2 | 8.7 | 4.5 |

## TABLE VII

Tear Strength After Weather[illegible]eter Exposure
(% of Original)

| | | Specimens Cloth, Parachute Pack | | | | |
|---|---|---|---|---|---|---|
| | | Nylon | Nomex | Durette | Nomex-OG | PBI-II |
| Control | (lbs) Tear Strength | 42.4 | 25.8 | 9.8 | 21.1 | 11.7 |
| Fifty (50) Hours | (lbs) Tear Strength | 19.0 | 9.8 | 4.5 | 12.5 | 5.2 |
| | % Retain | 44.80 | 37.8 | 46.0 | 59.25 | 44.4 |
| One Hundred (100) Hours | (lbs) Tear Strength | 4.9 | 5.9 | 2.8 | 8.9 | 4.3 |
| | % Retain | 11.55 | 22.8 | 28.5 | 42.12 | 36.7 |
| One Hundred Fifty (150) Hours | (lbs) Tear Strength | 4.0 | 5.5 | 2.2 | 8.7 | 4.5 |
| | % Retain | 9.45 | 21.3 | 22.4 | 41.25 | 38.5 |

TABLE VIII

Characteristics of PBI I and II Fabrics

| Characteristic Evaluated | PBI-1 | PBI-II |
|---|---|---|
| **Breaking Strength** | | |
| Control-lbs. /inch | 160.2 | 118.0 |
| 50 hrs | 109.4 | 97.5 |
| 100 hrs | 89.2 | 89.6 |
| 150 hrs | 64.2 | 89.7 |
| **Elongations, %** | | |
| Control | 25.5 | 19.6 |
| 50 hrs | 9.4 | 12.6 |
| 100 hrs | 7.7 | 7.4 |
| 150 hrs | 7.1 | 6.6 |
| **Tear Strength** | | |
| Control Pounds | 38.3 | 11.7 |
| 50 hrs | 17.7 | 5.2 |
| 100 hrs | * | 4.3 |
| 150 hrs | * | 4.5 |

*Tore diagonally across tongue

TABLE IX

Construction and Physical Properties

| Property | Nylon I | | | | Nylon II | | | |
|---|---|---|---|---|---|---|---|---|
| | | Accelerated Weather Hours | | | | Accelerated Weather Hours | | |
| | Construction | 50 | 100 | 150 | Construction | 50 | 100 | [illegible] |
| Weave | Plain | | | | Plain | | | |
| Yarns/Inch-W | 63 | | | | 60 | | | |
| Yarns/Inch-F | 45 | | | | 47 | | | |
| Thickness Inches | .013 | | | | .0135 | | | |
| Weight (oz/yd$^2$) | 6.59 | | | | 6.45 | | | |
| Elongation % | 39 | | | | 37.6 | | | |
| Break Strength | 333.8 | 161.6 | 73 | 57.1 | 259 | 215 | 204.25 | 170.66 |
| Retain Strength % | | 48.40 | 21.90 | 17.05 | | 83.01 | 78.76 | 65.89 |
| Tear Strength | 42.4 | 19.0 | 4.9 | 4.0 | 37.1 | 28.4 | 23.7 | 20.[illegible] |
| Retain Strength % | | 44.80 | 11.55 | 9.45 | | 76.56 | 63.89 | 53.49 |

TABLE X

Summary of Data on Two Nylon and Two PBI Fabrics

| Characteristic Evaluated | Nylon-I | Nylon-II | PBI-I | PBI-II |
|---|---|---|---|---|
| Breaking Strength | | | | |
| Control-lbs./inch | 333.8 | 259.0 | 160.2 | 118.0 |
| 50 hrs.-% Retained | 48.4 | 83.0 | 68.3 | 82.6 |
| 100 hrs-% Retained | 21.9 | 78.9 | 55.6 | 76.0 |
| 150 hrs-% Retained | 17.1 | 65.9 | 40.0 | 76.1 |
| Elongation | | | | |
| Control-% | 39.0 | 37.6 | 25.5 | 19.6 |
| 50 hrs.-% Retained | 66.7 | 88.8 | 37.9 | 64.2 |
| 100 hrs-% Retained | 39.7 | 84.5 | 30.2 | 37.7 |
| 150 hrs-% Retained | 32.3 | 66.0 | 27.8 | 33.7 |
| Tear Strength | | | | |
| Control-Pounds | 42.4 | 37.1 | 38.3 | 11.7 |
| 50 hrs.-% Retained | 44.8 | 76.6 | 46.2 | 44.4 |
| 100 hrs-% Retained | 11.6 | 63.9 | * | 36.7 |
| 150 hrs-% Retained | 9.4 | 53.5 | * | 38.5 |

*Tore diagonally across the specimen

polymer and to some extent spinning and drawing conditions. Further research in this area is still in progress.

## SECTION IV

## CONCLUSION

Changes in the characteristics of a fibrous material including, among others, color, breaking strength, and elongation are in proportion to light intensity and time of exposure. Although 150 hours in the Weatherometer is a relatively short time, the exposure duration and light intensity are sufficient to engender changes predictive of subsequent performance.

The comparatively poor U-V resistance of the first nylon evaluated is attributed to the fact that U-V resistant yarns and finishes were not used in the specific parachute pack fabric removed from inventory for use in the program. To ascertain the correctness of this conclusion, a second nylon pack fabric (nylon-II) CONFORMING TO THE REQUIREMENTS of MIL-C-7219C was taken from stock. It was subjected to duplicative evaluation and analysis with substantially different results. As indicated in Table IX this second material had a greater resistance to U-V degradation as compared to the first nylon evaluated. For pack fabrics, the use of nylon should be discontinued because of its low melting temperature (482°F) and its flammability. A decided advantage in replacing nylon with a nonflammable material in personnel parachutes is the ability of these materials to withstand flash fires sufficiently long to permit egress from burning aircraft.

The PBI-II was found to have U-V stability superior to that of both the dyed and undyed Nomex and Durette (Figures 1-4 and Tables III through X) with respect to breaking strength. The dyed Nomex retained slightly more tear strength than the PBI-II but the % strength retained difference was only

a few percentage points. The thickness of the PBI-II (which was thinner and lighter in weight) might have been one reason for the difference in retained tear strength.

The dye used to obtain the Olive Green color and the Durette treatment for flameproofing appear to act as U-V inhibitors on the fabrics so treated. Their resistance to degradation was improved over that exhibited by undyed Nomex. Since the retained properties are not as good as the specification nylon (II), separate programs have been initiated to develop chemical additives to enhance the U-V resistance of these two fibers (PBI and Nomex). Little is known of the progress being made by E.I. du Pont de Nemours, Inc. to improve the U-V resistance of Nomex.

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13. ABSTRACT


Parachute pack fabrics utilized in personnel decelerators are subjected to extensive solar radiation (primarily U-V) during in flight missions and related ground handling situations.

Parachute pack replacements during the service life of a parachute results in additional costs, unnecessary and excessive out of commission time, and the requirement for larger inventories.

The data presented herein covers the work accomplished on an internal program to study the reaction and resistance of various types of actual and candidate parachute pack fabrics to ultra-violet exposure.

As expected Type 330 nylon was the most U-V resistant material evaluated. PBI-II and dyed Nomex had approximately the same percentage retention of breaking and tear strength but were not equal to U-V resistant nylon.


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|---|---|---|---|---|---|---|
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| Parachute materials | | | | | | |
| Parachute pack materials | | | | | | |
| PBI VS Ultraviolet exposure | | | | | | |
| Nomex vs Ultraviolet exposure | | | | | | |
| Type 330 Nylon | | | | | | |